Marine plankton, atmospheric sulfur and Arctic climate change

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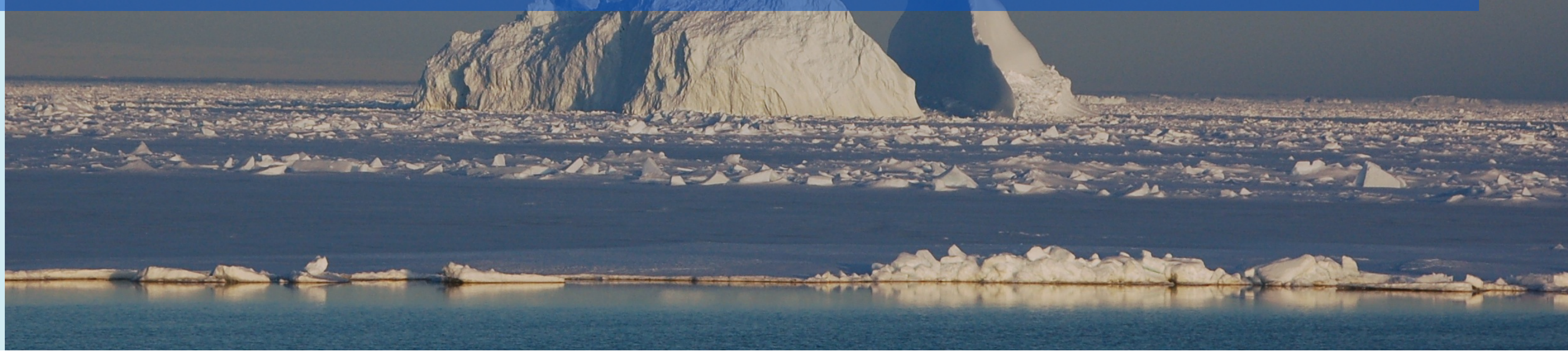

Canada Excellence Research Chair in Remote Sensing of Canada's New Arctic Frontier

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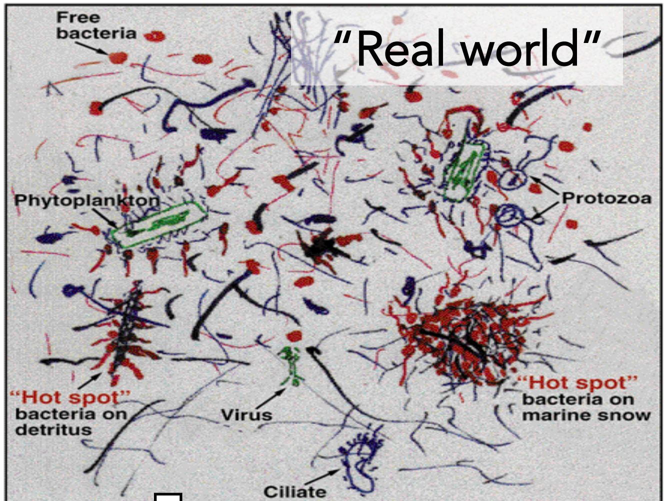
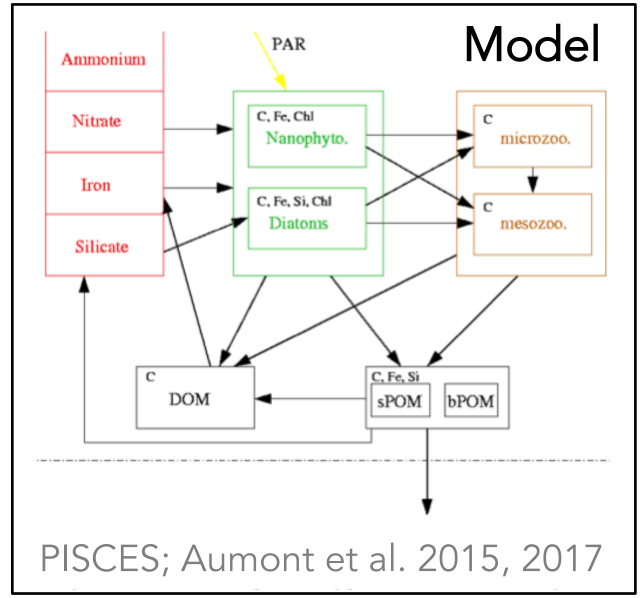
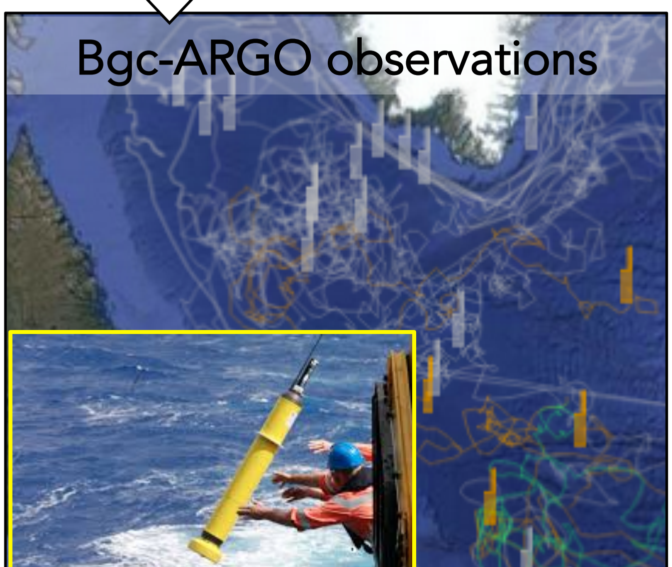
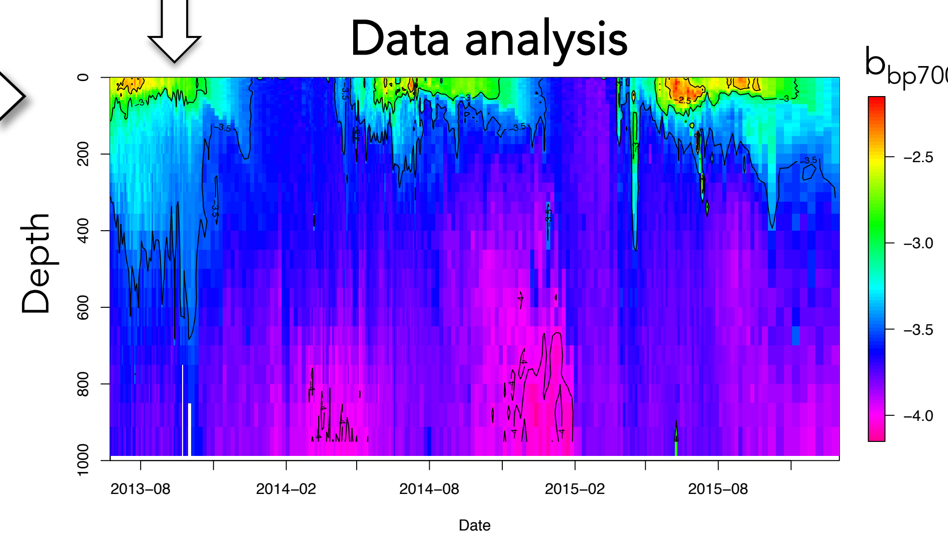
New ORCAS project: ORganic CArbon Sequestration in the ocean

Constraining model predictions with novel high-resolution observations







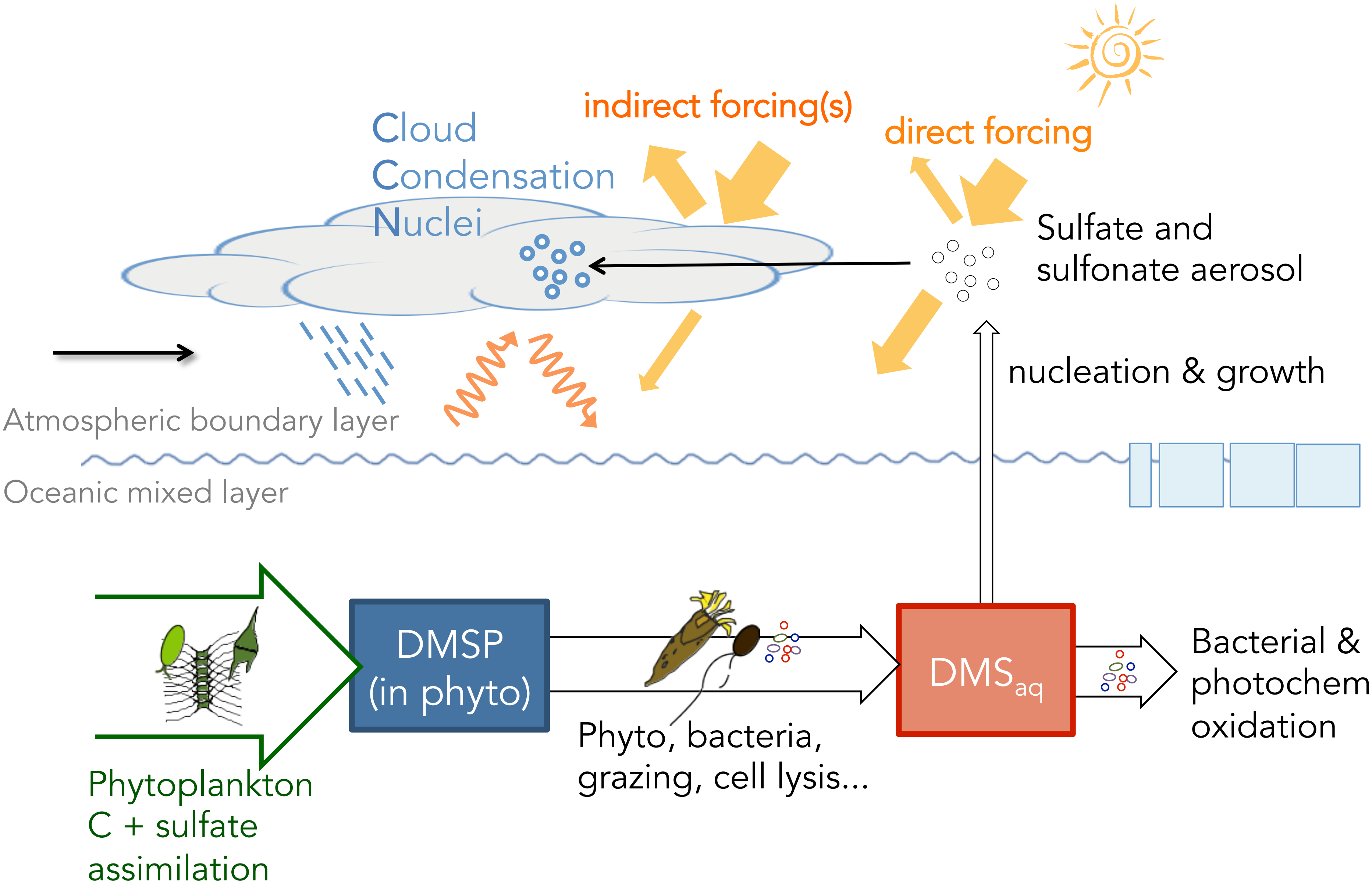


MareNostrum4 supercomputer @BSC. https://www.bsc.es/ → 80% European network

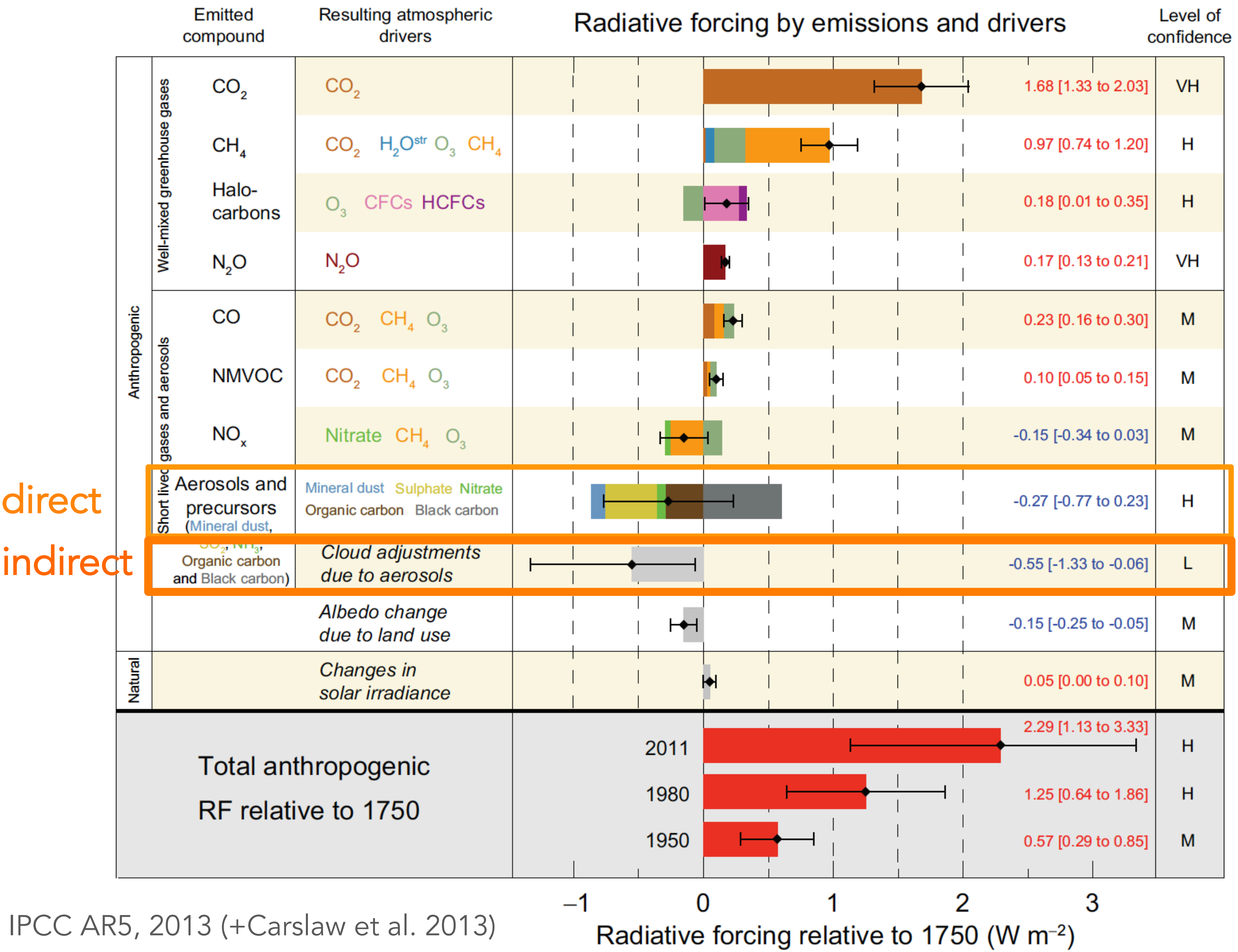
OUTLINE

1. Introduction, hypotheses, goals
2. Methods: DMS-SAT algorithm
3. Results: interannual emission trends and controlling factors
4. Future: ice-free summer, changing (phyto)plankton dynamics
5. Example applications for ocean-atmosphere studies
6. Conclusions

DMS emission: from plankton to clouds



Charlson et al. 1987, Simó 2001, Levasseur 2013



IPCC AR5, 2013 (+Carslaw et al. 2013)

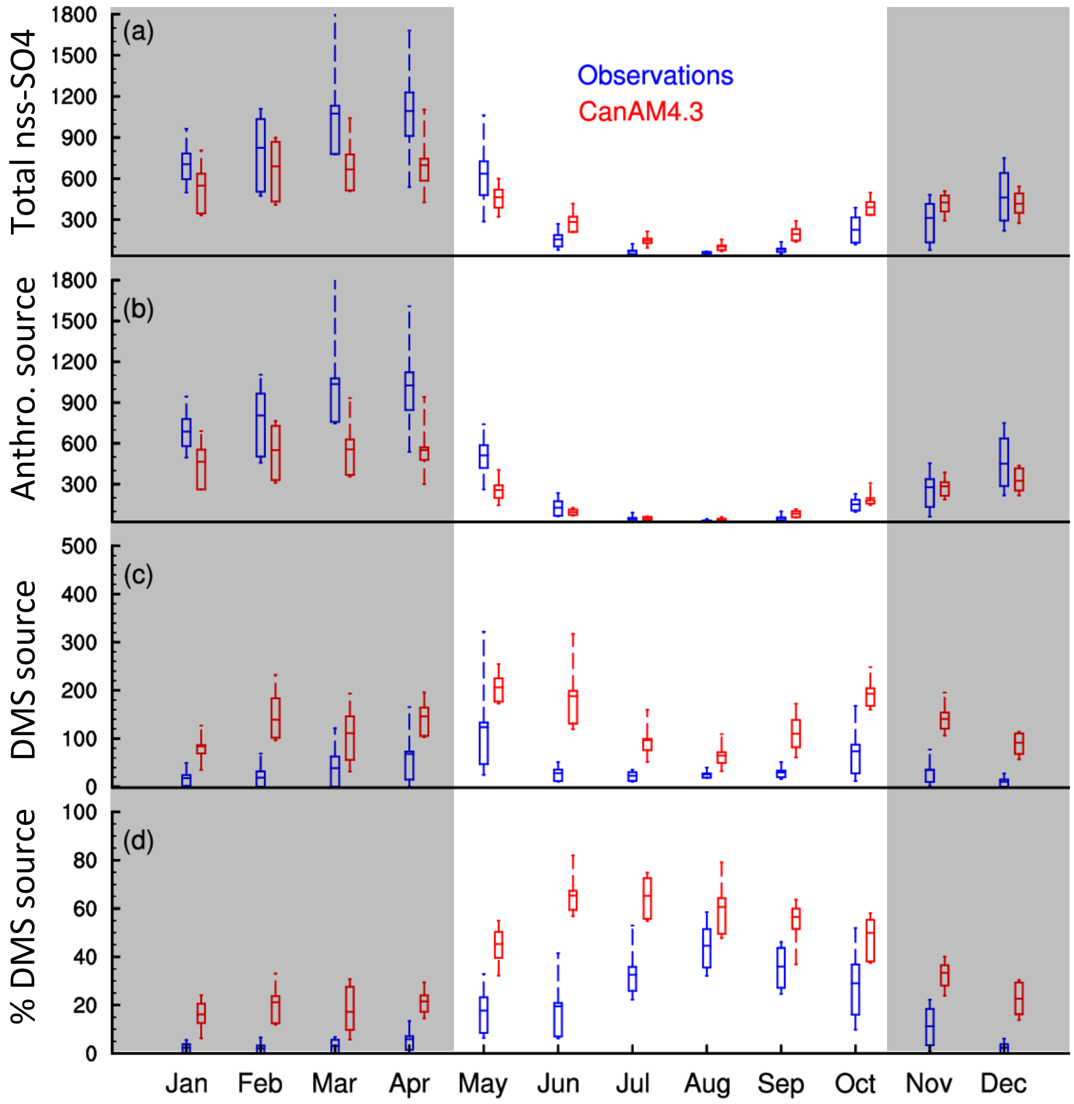
Sulfur sources to the Arctic atmosphere

Arctic Summer:

- ✓ low pollution transport
- ✓ high photochemistry
- ✓ high biological activity

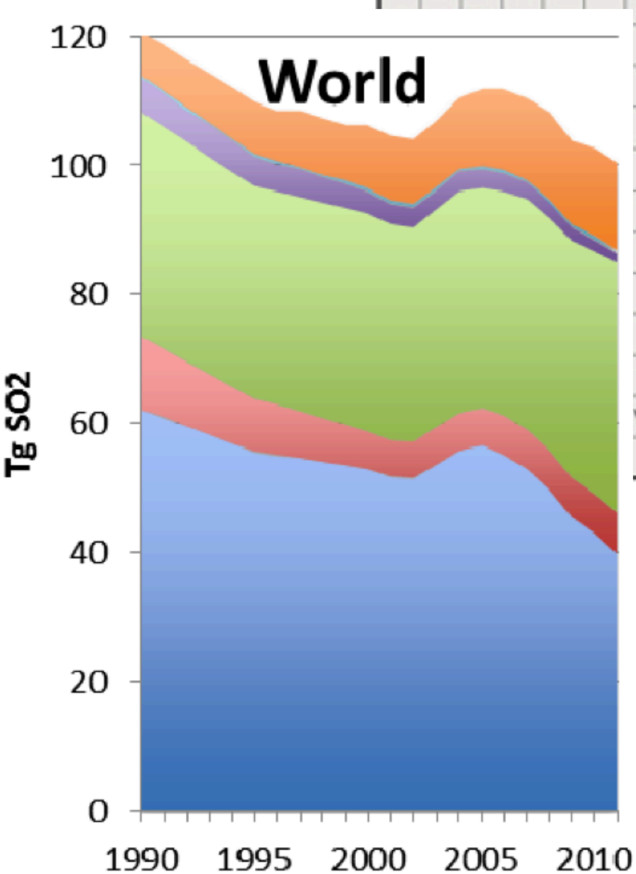
⇩

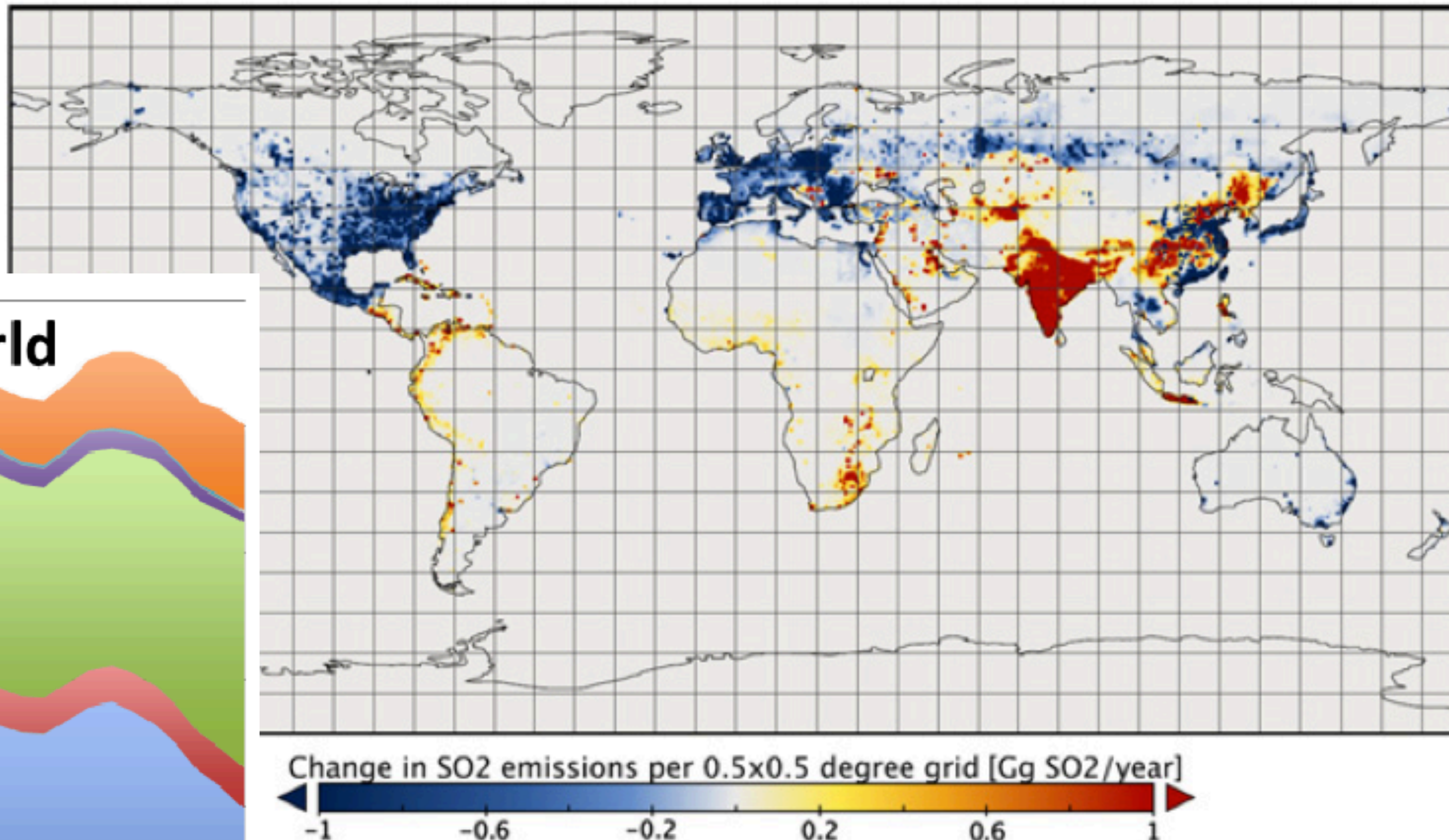
DMS can control new particle formation (= nucleation)



Leaitch et al. 2013, Mungall et al., 2016, Mahmood et al. 2018 ACPD

Declining anthropogenic SO_2 emissions

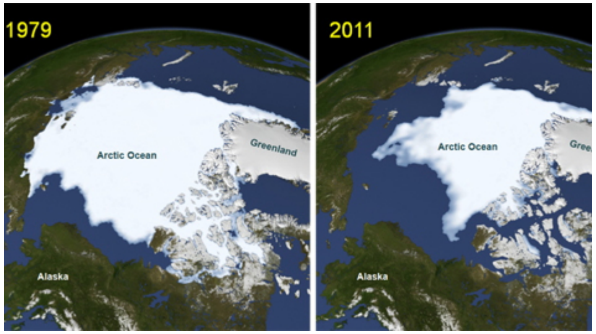




Change between 2010 and 2005

Klimont et al. 2013

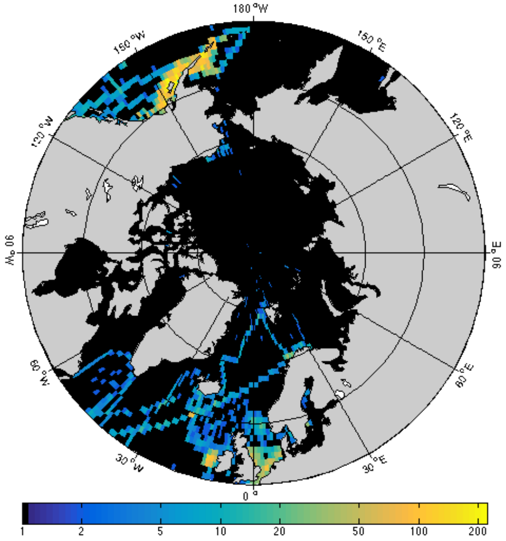
Hypotheses and goals



Hypotheses:

- Arctic Ocean DMS emission is increasing as summer sea ice recedes and more ocean surface is exposed to the atmosphere.
- Changing DMS emission could alter aerosol and cloud radiative forcing.

Problem: Sparse *in situ* data and sampling difficulties hinder DMS emission estimates.



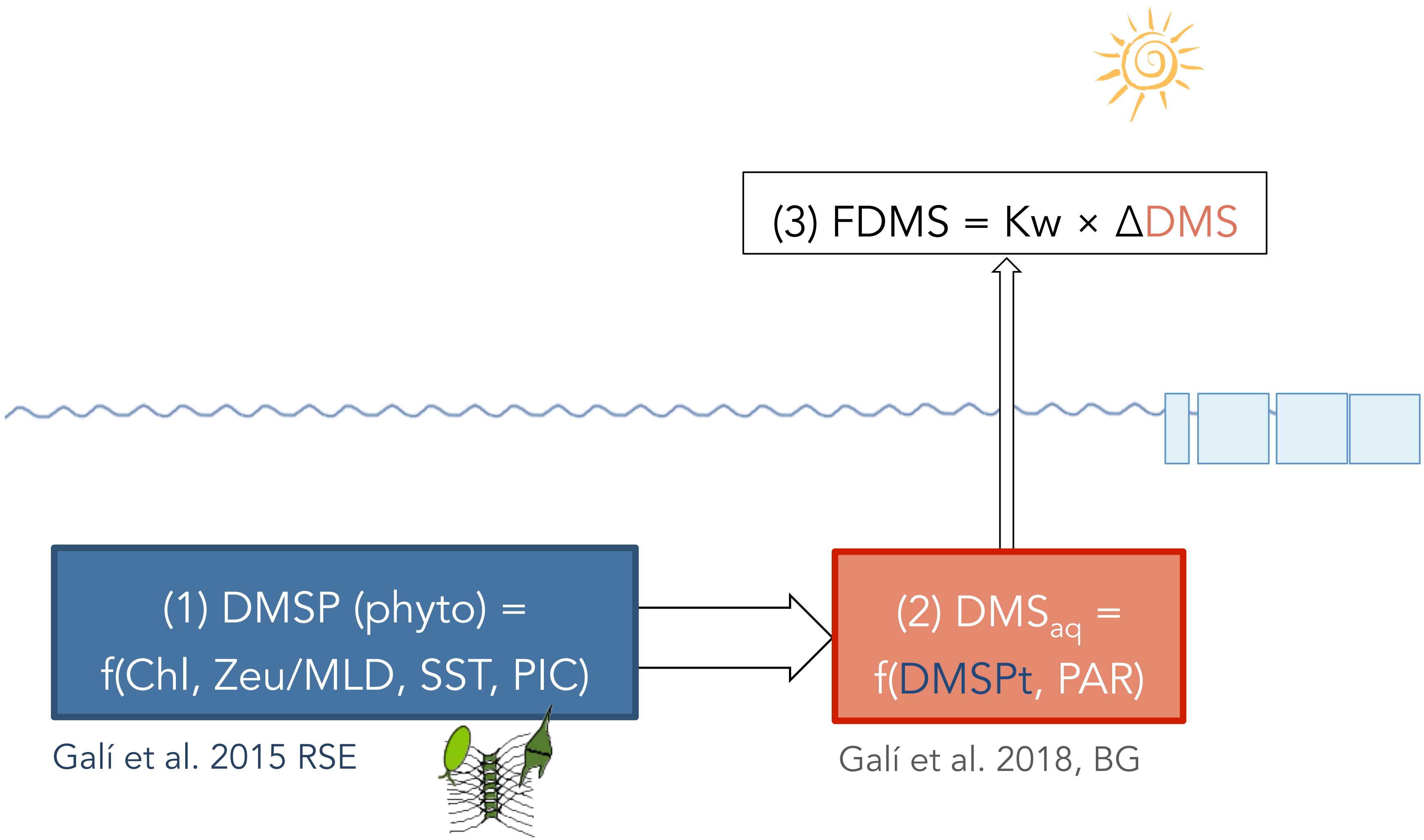
Goals

- Develop an algorithm to estimate marine DMS emission from satellite data.

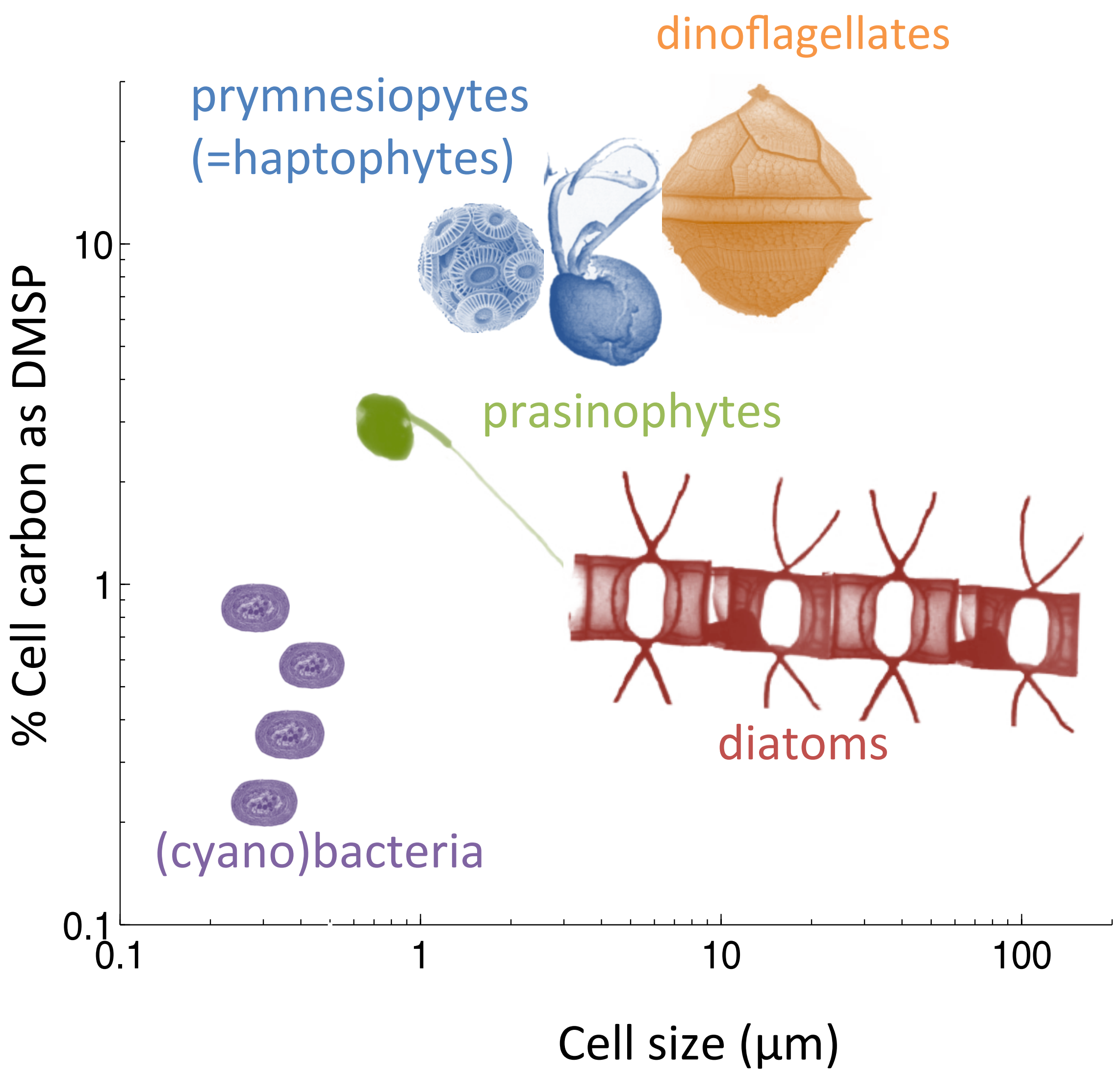
→ see Neukermans, Harmel, Galí et al. 2018

- Apply it to produce multiyear time series of DMS emission in the Arctic.

2. Algorithm — Estimating sea-air DMS flux in 3 steps



Step 1: Sea-surface DMSPt (in phyto.)

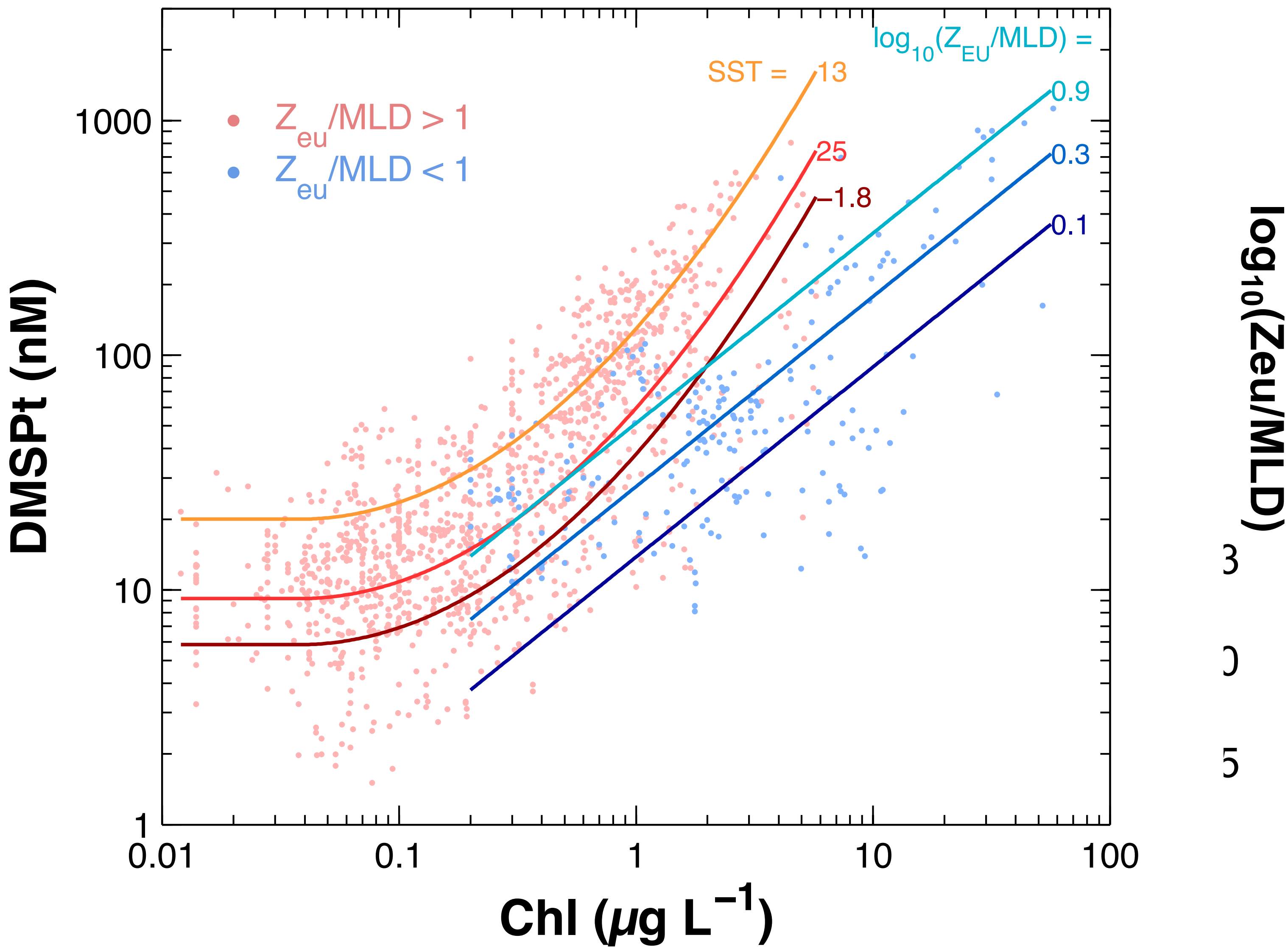


Proposed functions:

- ✓ Osmolyte
- ✓ Antioxidant
- ✓ Methyl donor
- ✓ Cryoprotectant

see McParland & Levine 2018

2. Algorithm — Step 1: Sea-surface DMSPt (in phyto.)

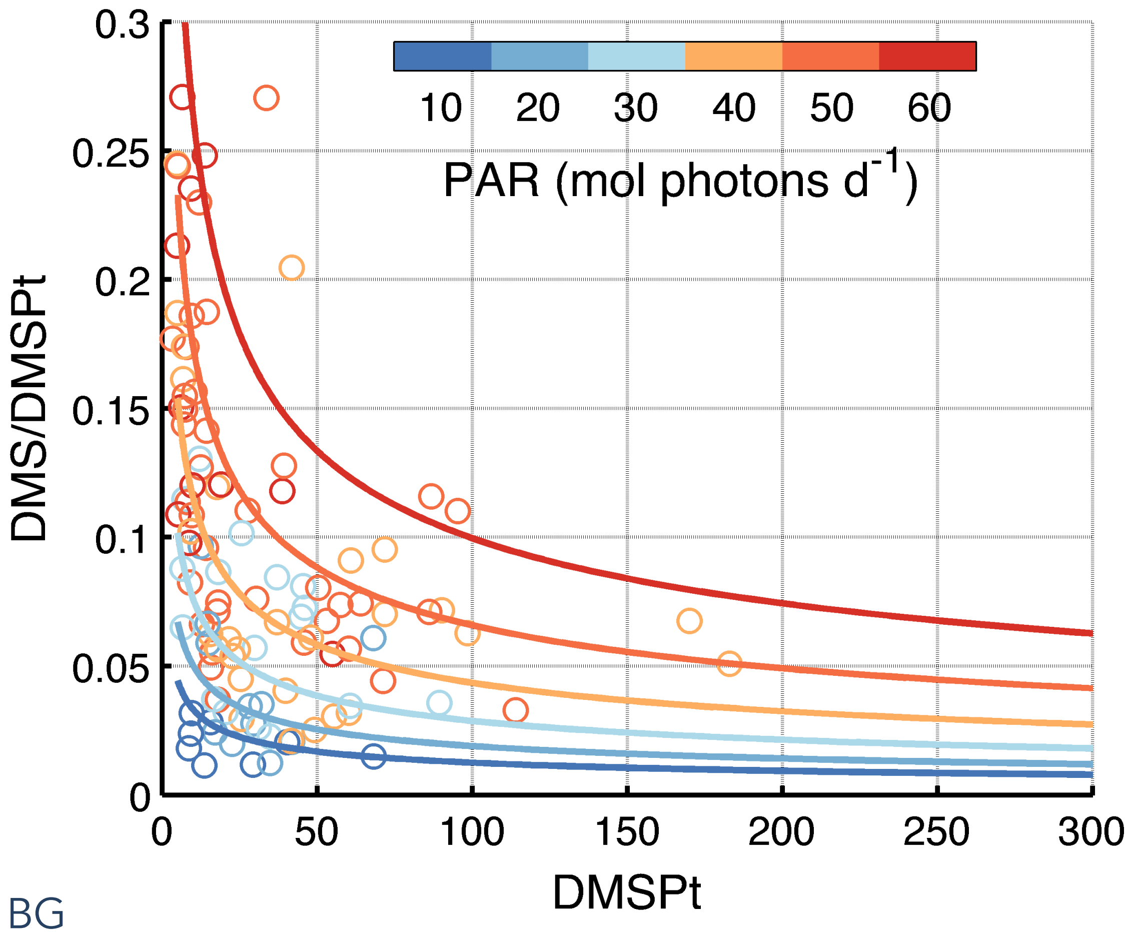


Galí et al. 2015 RSE

Step 2: Sea-surface DMS (dissolved gas)

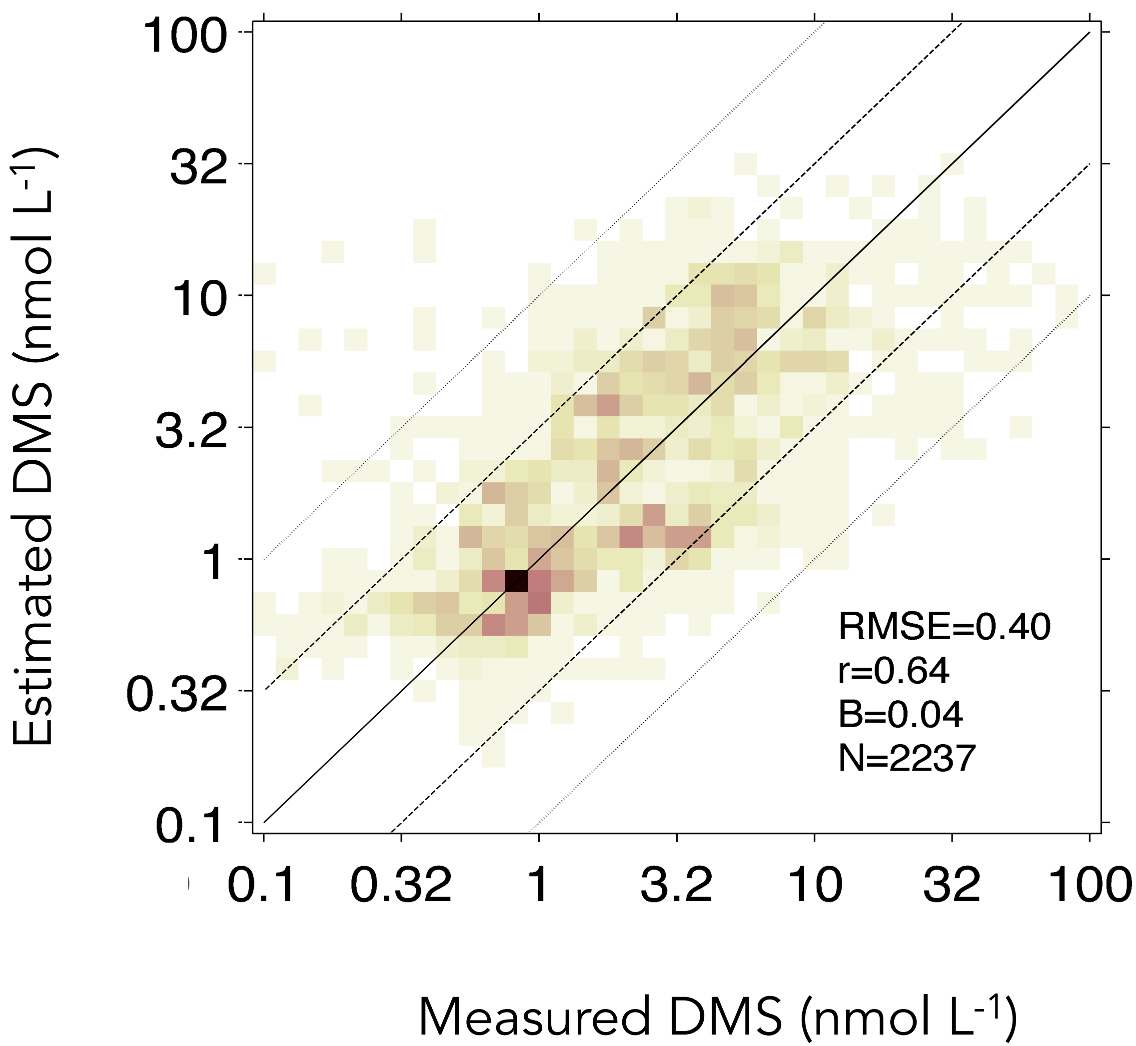
$$\log_{10}\text{DMS} = \alpha + \beta \log_{10}\text{DMSPt} + \gamma\ \text{PAR}$$

$$0 < \beta < 1;\ \gamma > 0$$



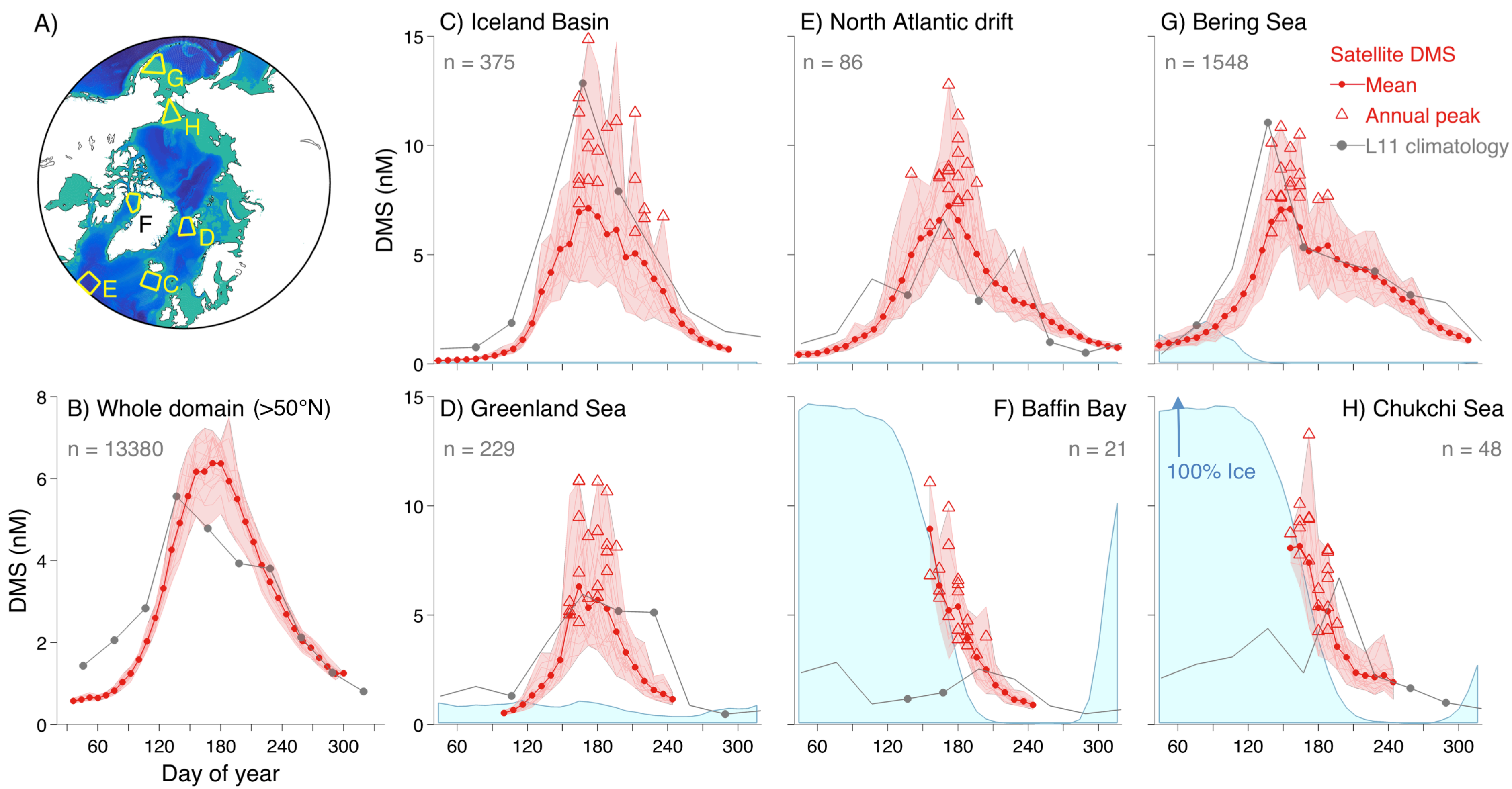
Galí et al. 2018 BG

Validation of step 1+2



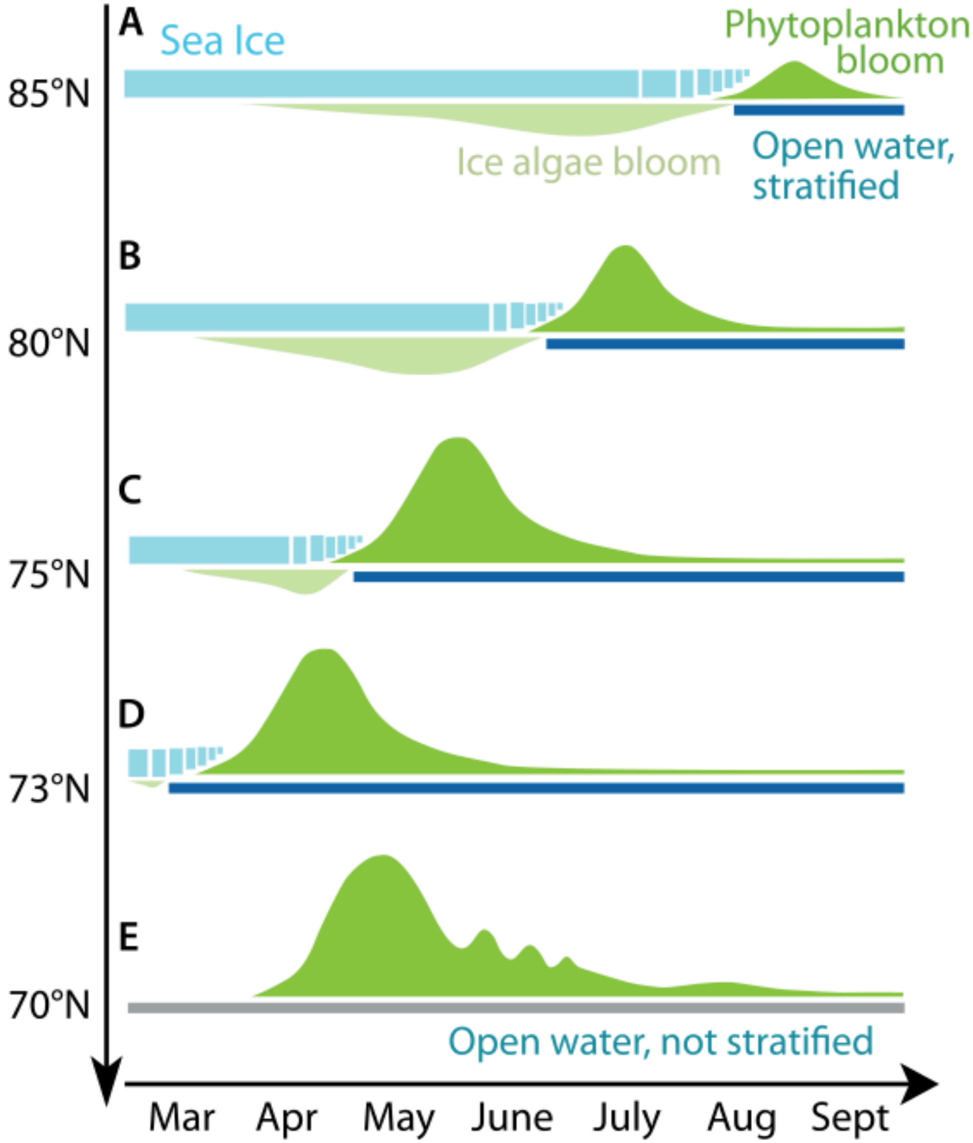
Galí et al. *submitted*

Seasonal DMS cycle: interannual variability



Galí et al. *submitted*

Seasonal DMS cycle: ice edge blooms

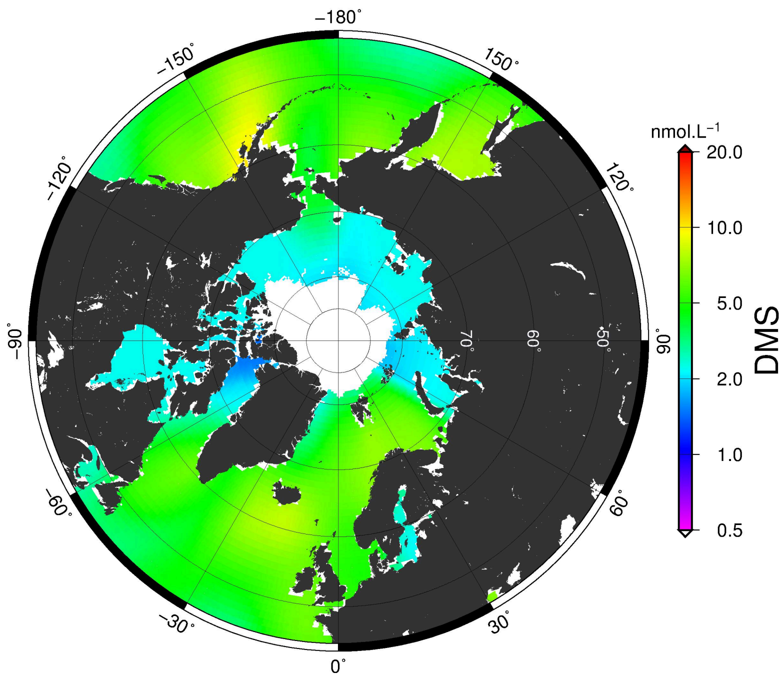


Wassmann & Reigstad 2011

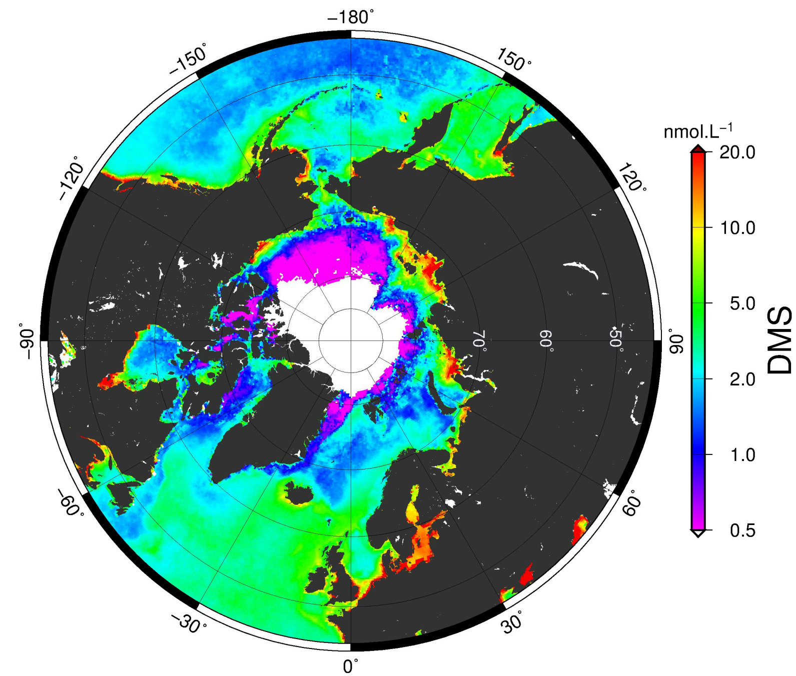
3. Results

Satellite view of summertime DMS

Gridded climatology



DMS-SAT1998-2018 climatology

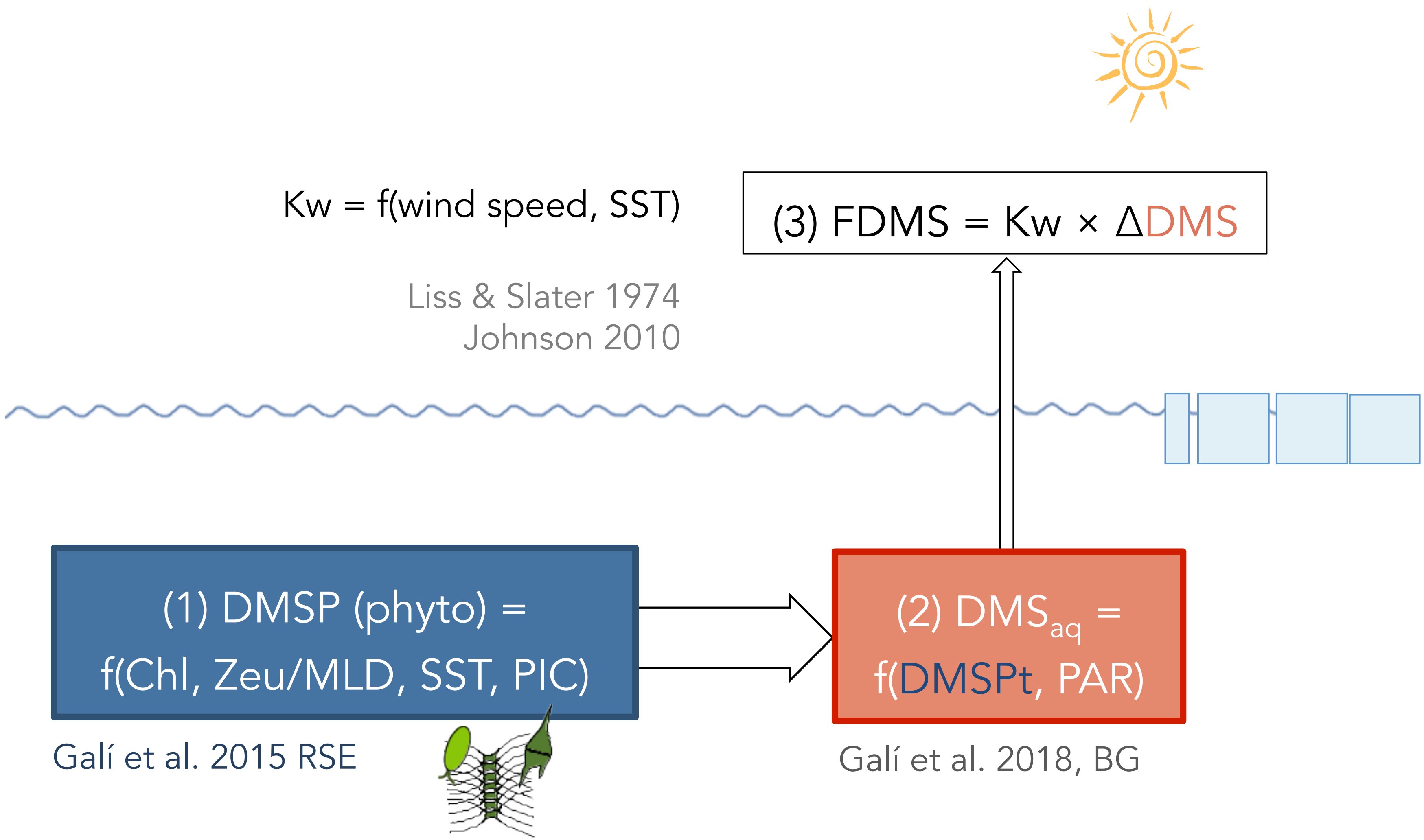


Lana et al. 2011

May-August means

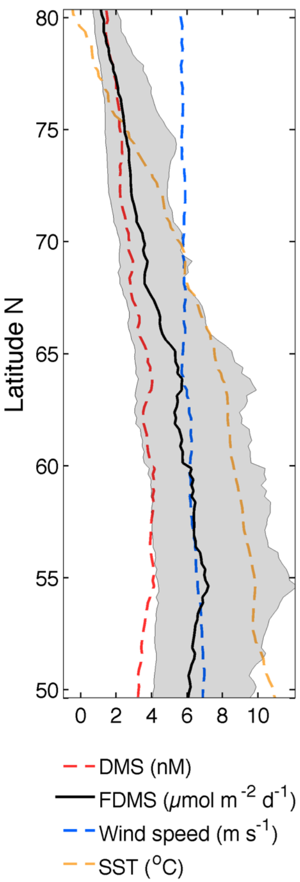
Galí et al. *submitted*

2. Algorithm — Sea-air DMS flux

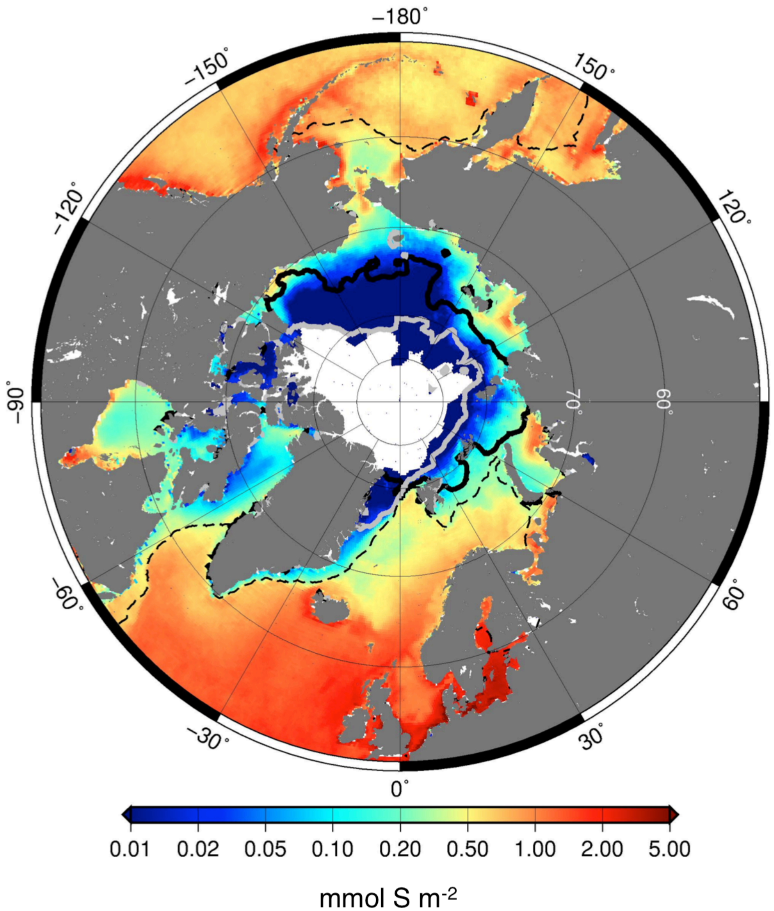


What controls mean summer DMS fluxes?

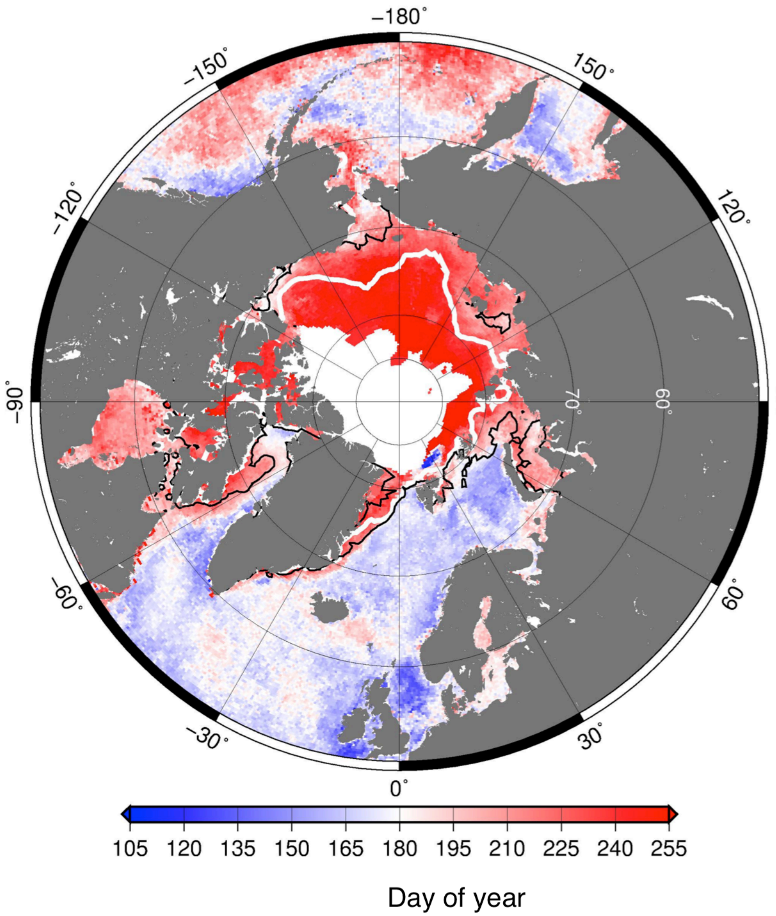
Latitudinal profiles



Integral DMS flux (May-August)

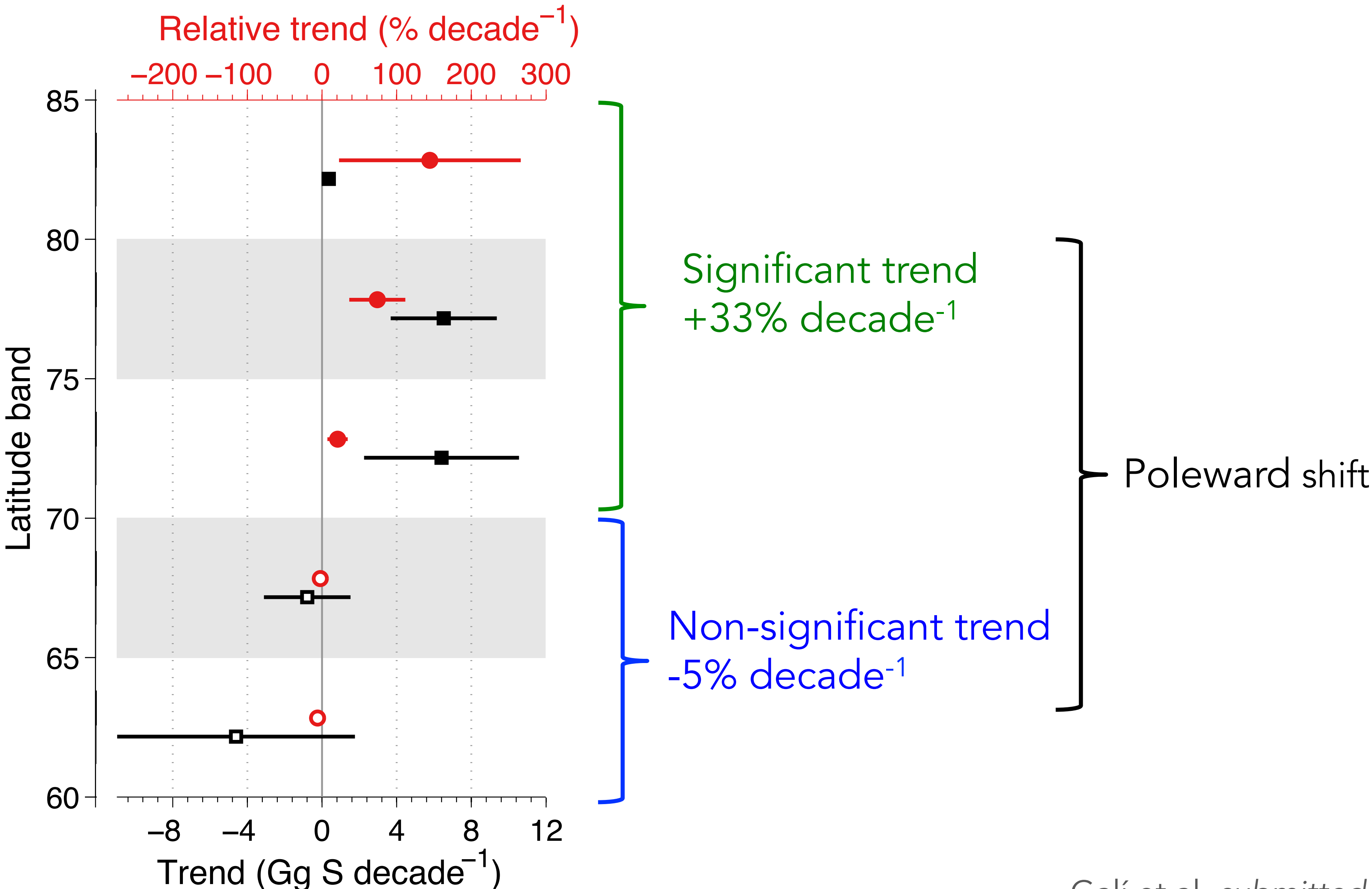


Timing of peak DMS flux



Galí et al. *submitted*

3. Results — Zonal DMS emission trends 1998-2016



Galí et al. *submitted*

3. Results — What controls emission trends north of 70°N?

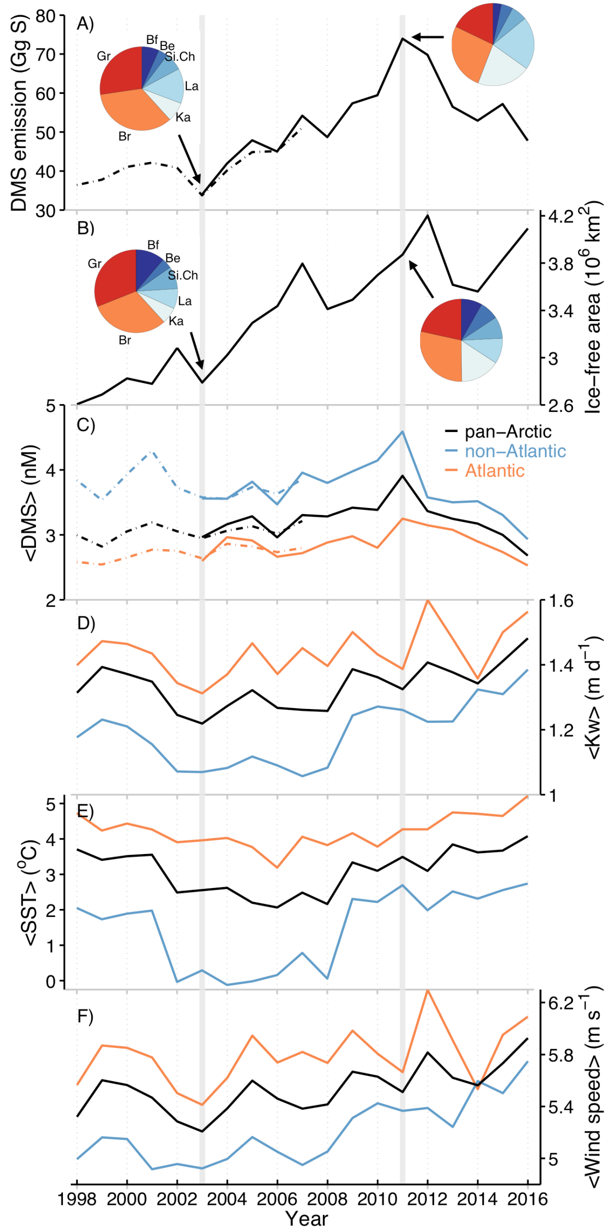
Non-monotonic trends and variable regional contributions

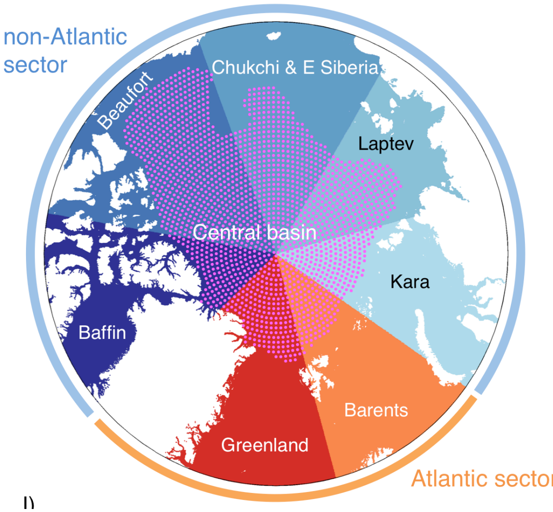
Due to variable ice retreat patterns

But also variable [DMS]

And sea-air gas exchange Kw

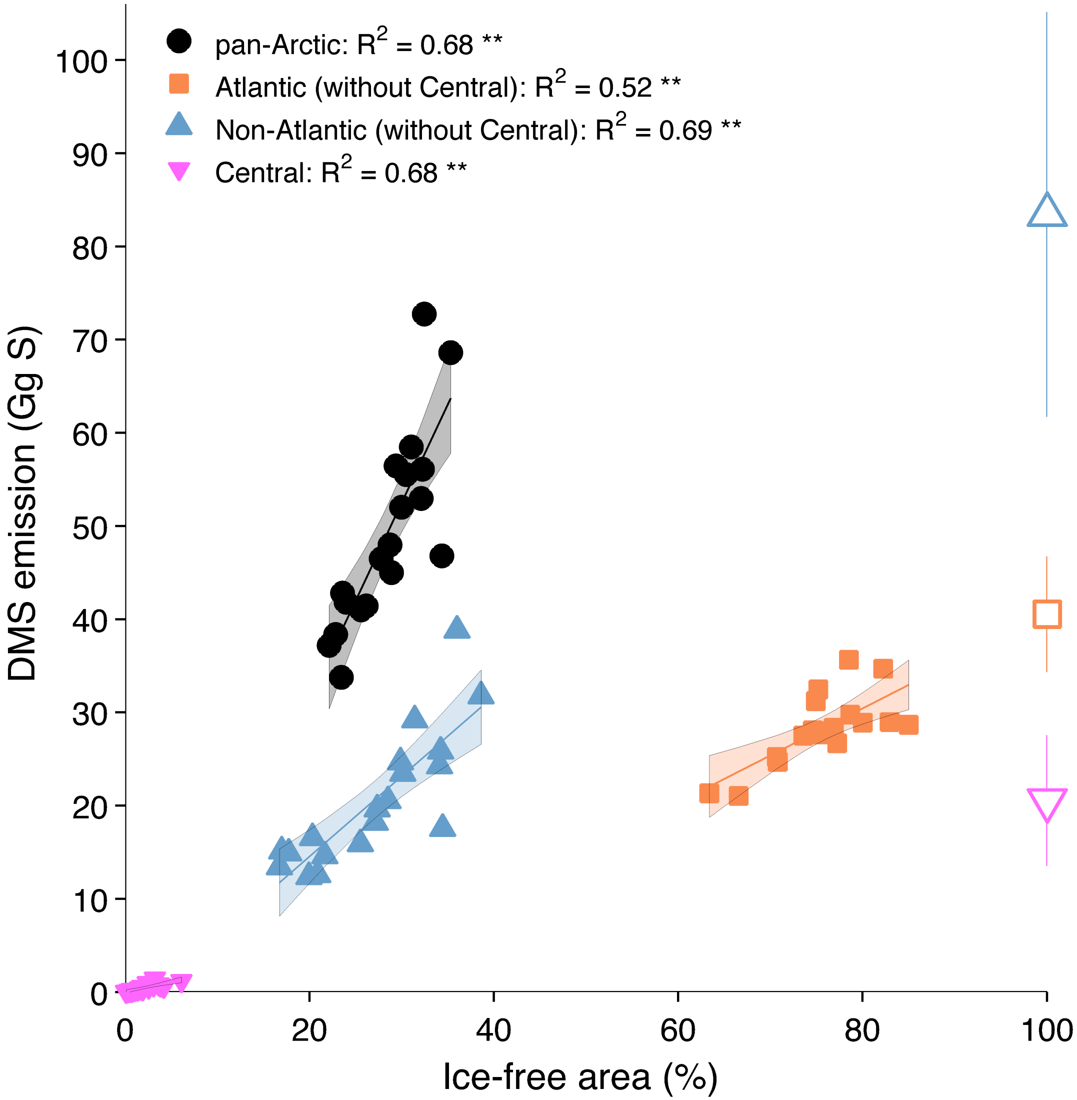
Key meteorological forcing

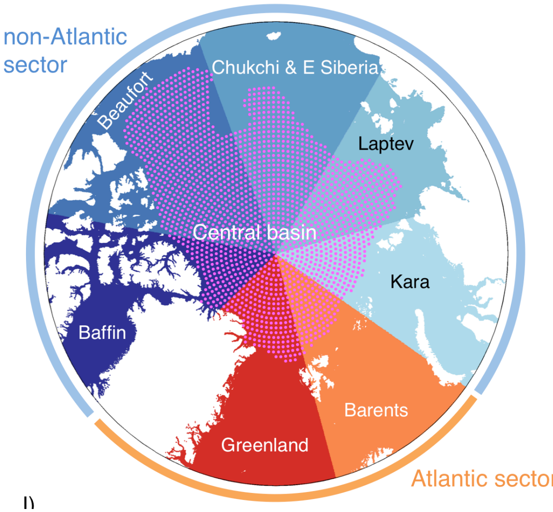




Galí et al. *submitted*

How much DMS emission in ice-free summer?



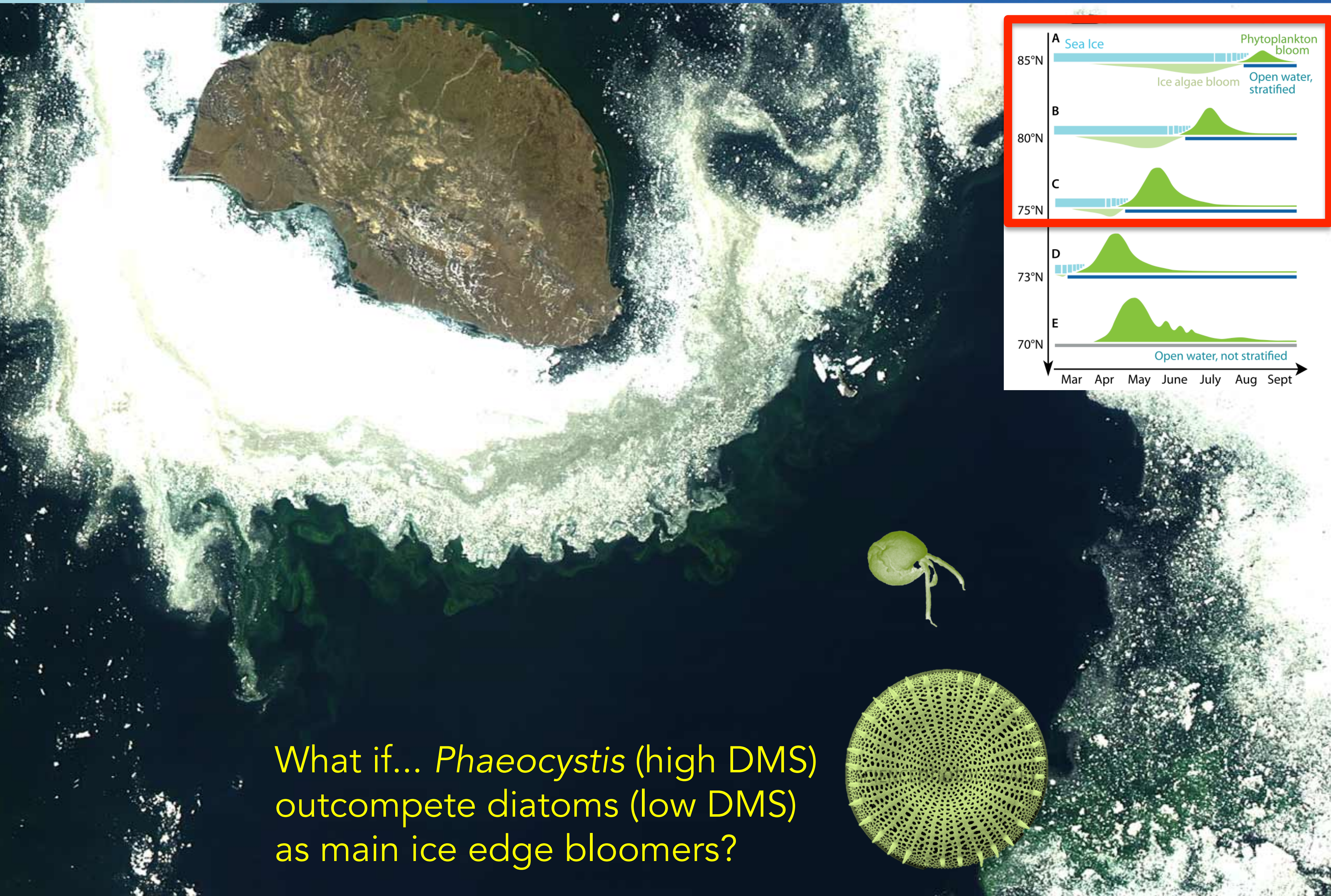


Extrapolation:

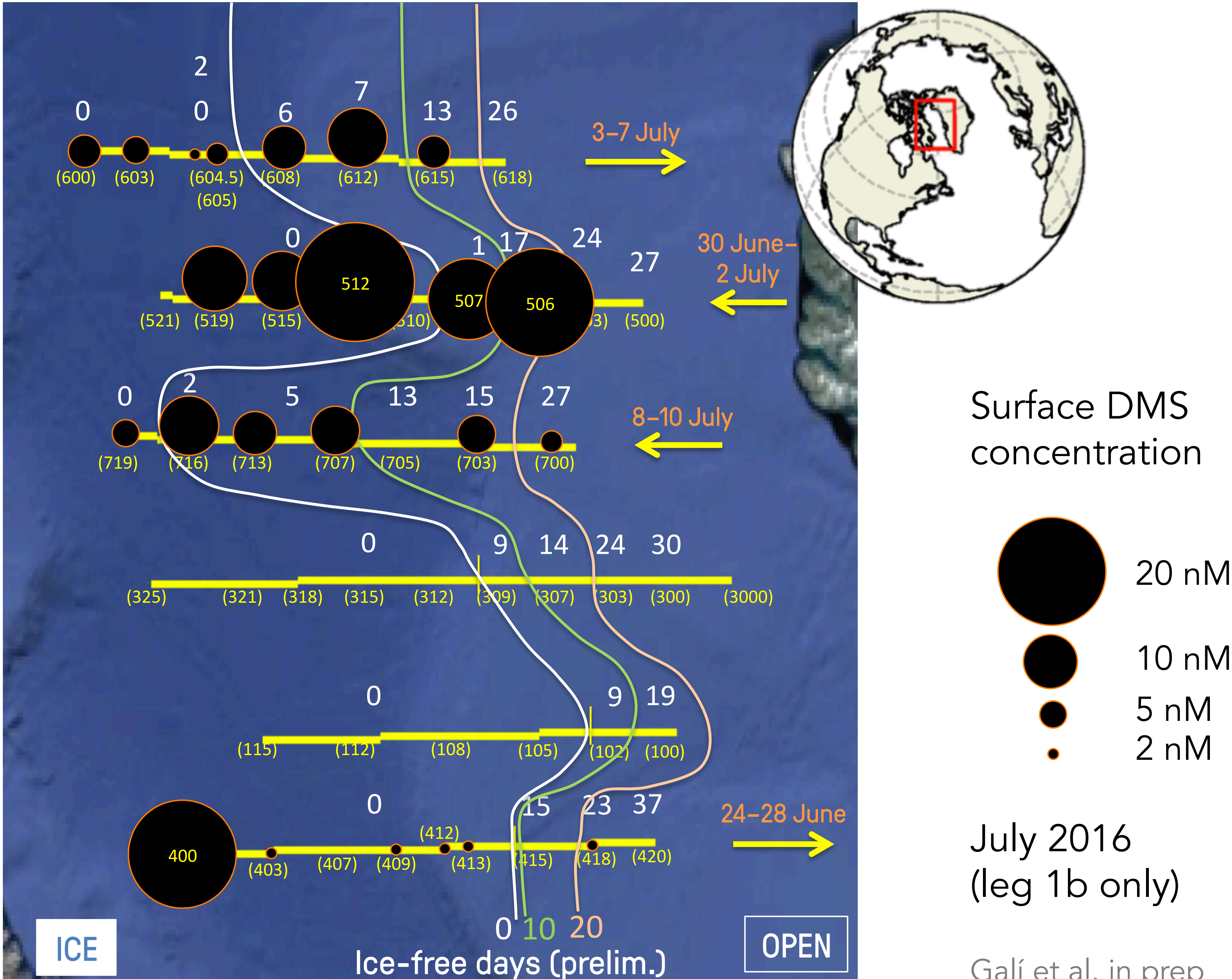
144 ± 66 Gg S per summer

Galí et al. *submitted*

4. Speculation... Future scenarios: can we trust extrapolations?

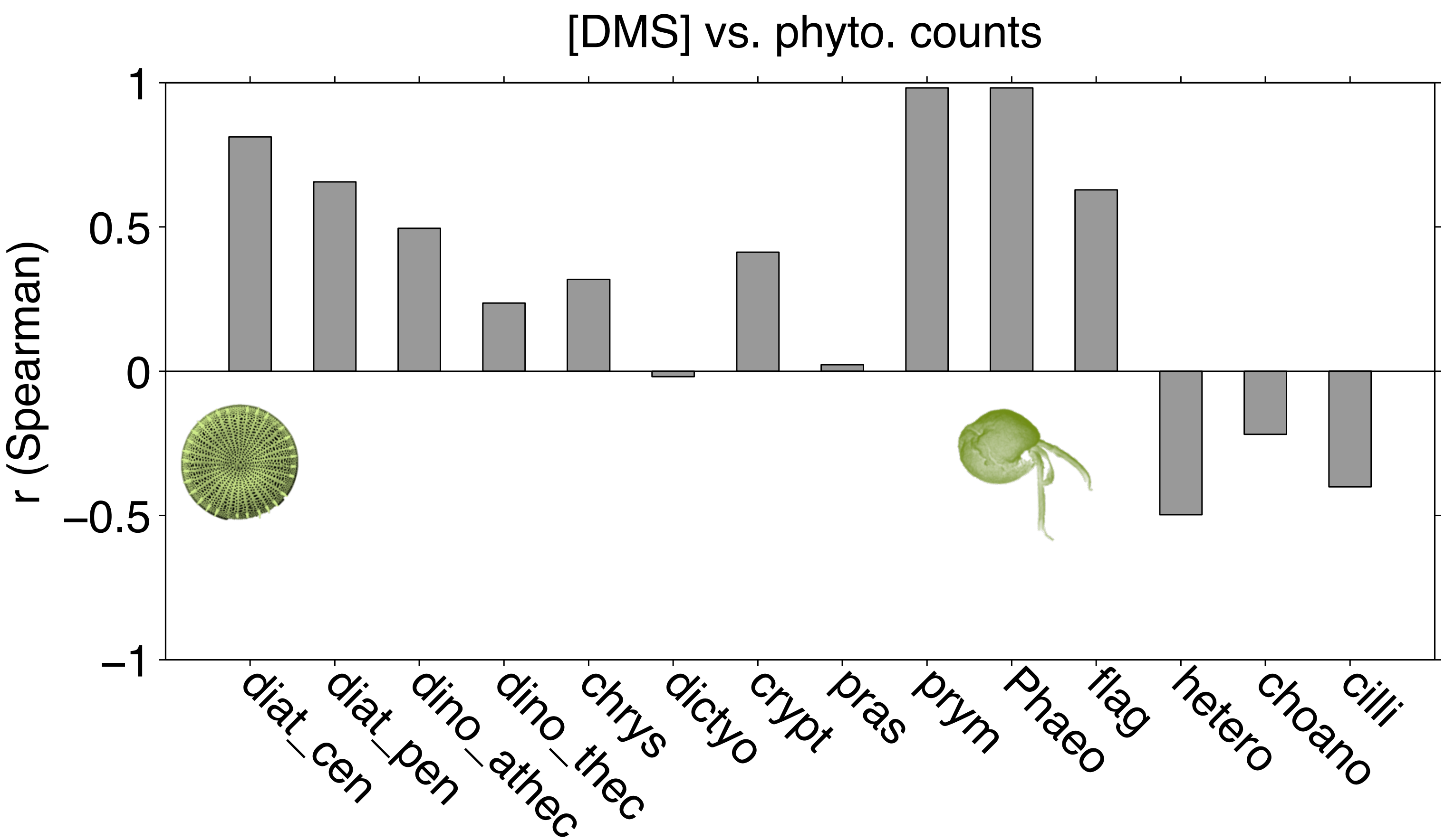


What if... *Phaeocystis* (high DMS) outcompete diatoms (low DMS) as main ice edge bloomers?



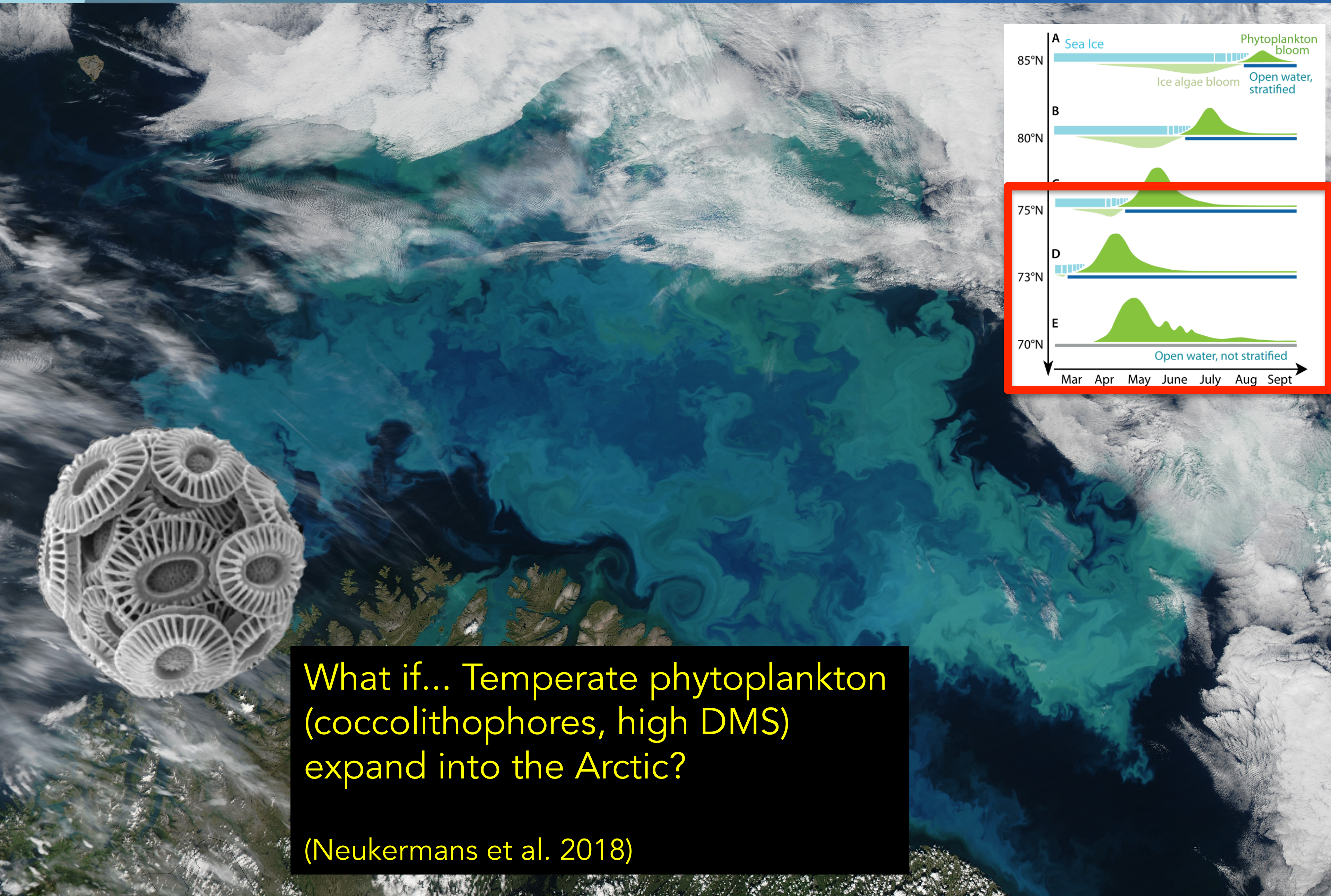
Galí et al. in prep

Future scenarios: can we trust extrapolations?



see Li et al. 2009, Blais et al. 2017

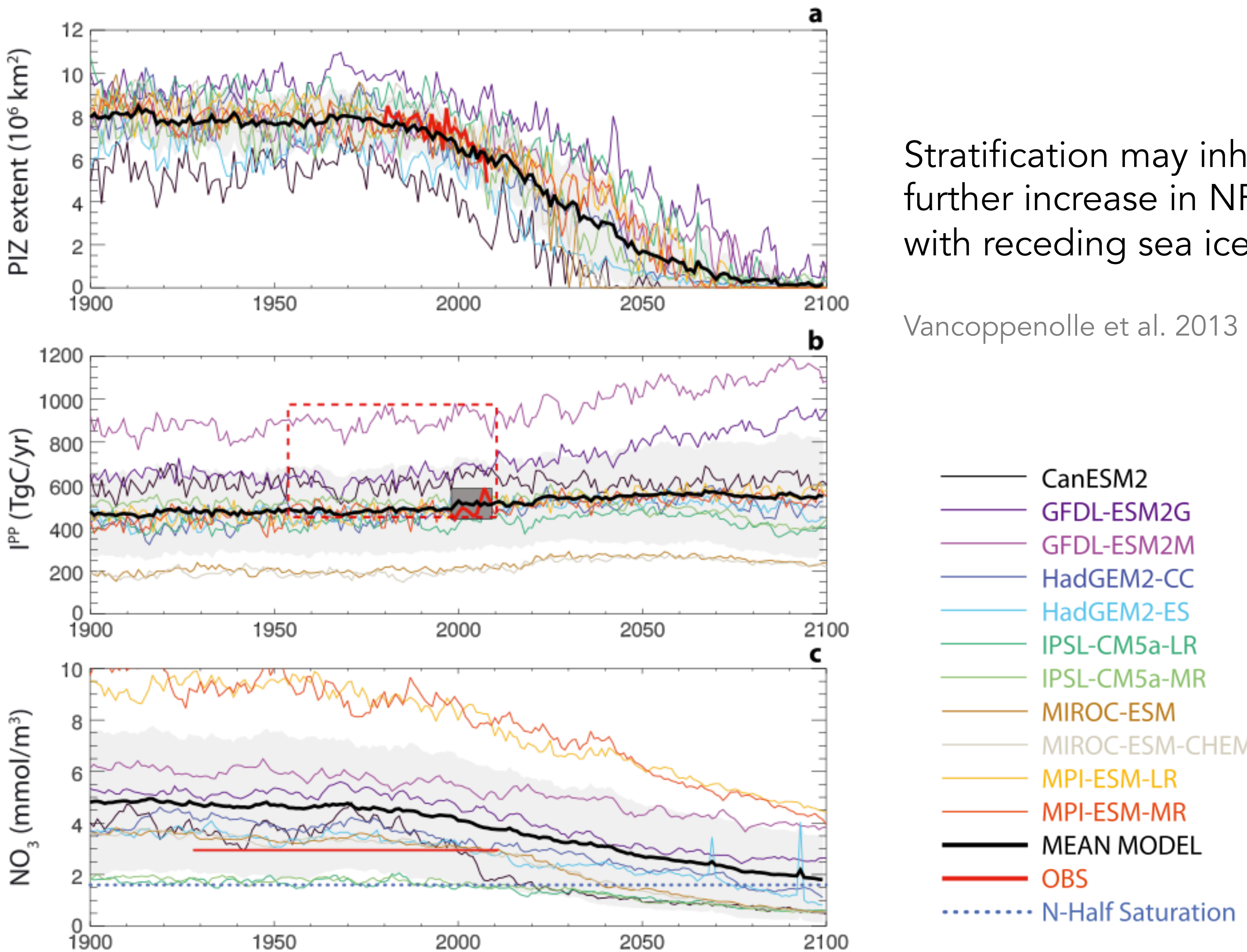
4. Speculation... Future scenarios: can we trust extrapolations?



What if... Temperate phytoplankton (coccolithophores, high DMS) expand into the Arctic?

(Neukermans et al. 2018)

4. Speculation... Future scenarios: what about projections?



Stratification may inhibit further increase in NPP with receding sea ice

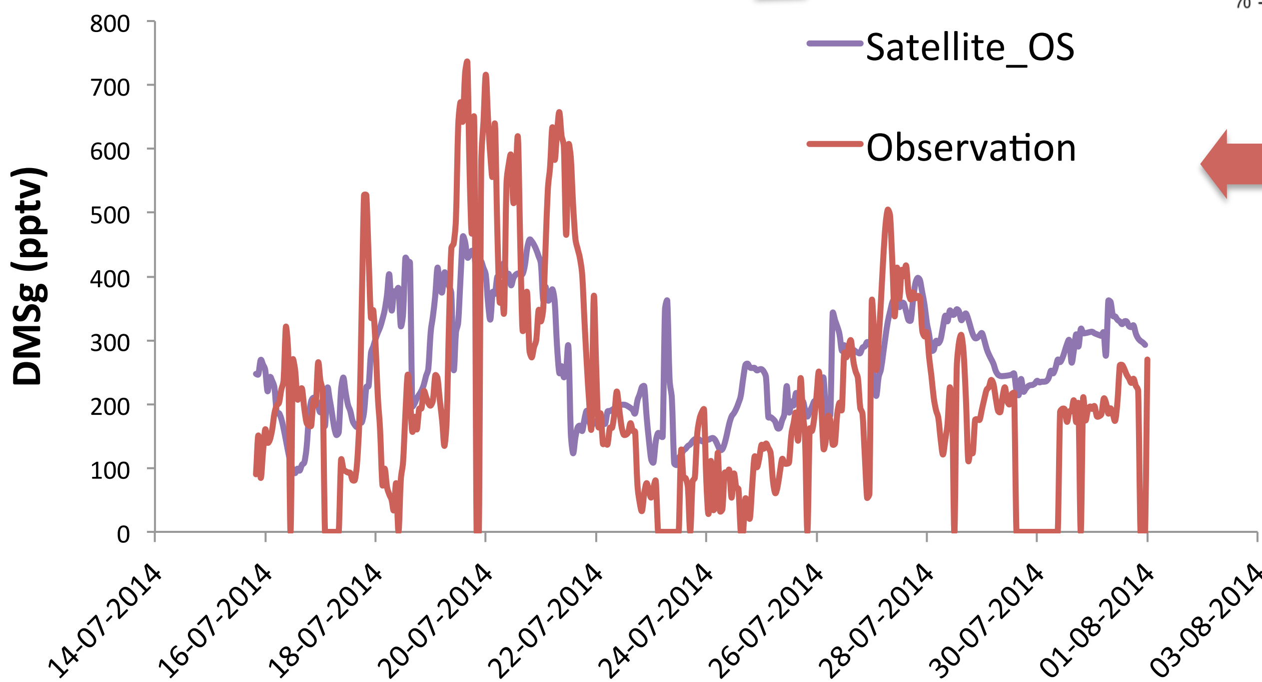
Vancoppenolle et al. 2013 GBC

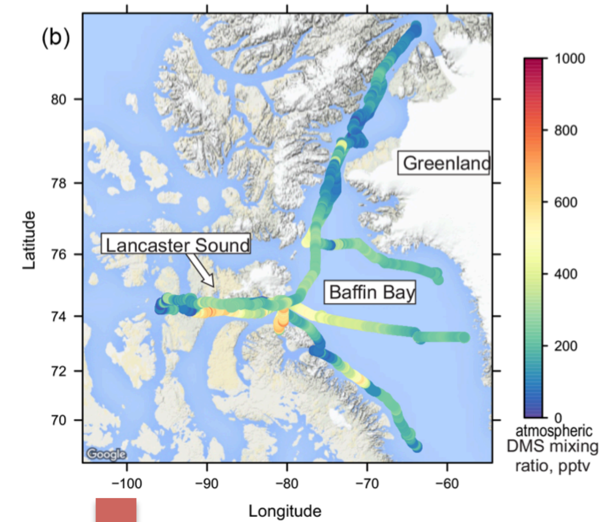
5. Ocean-atmosphere

Ex. 1: link to in situ atmospheric observations

DMS-SAT

GEM-MACH





Mungall et al. 2016

Ghahremaninezhad et al., *in prep.*

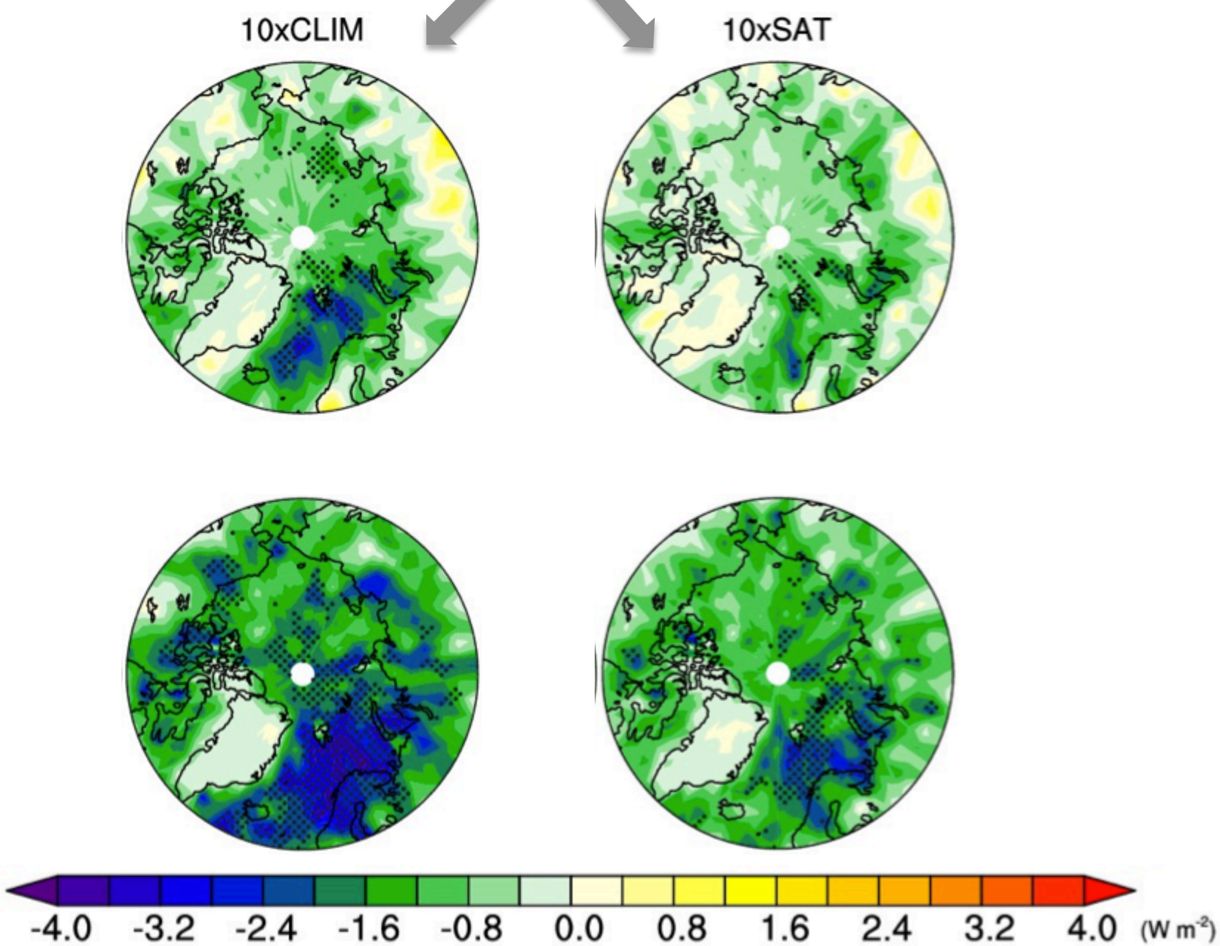
(also, Heintzenberg et al. 2017 ACP)

Ex. 2: input to Earth System model

Gridded climatology of in situ data
Lana et al. 2011

CanAM4.3

DMS-SAT



Cloud shortwave radiative forcing

Mahmood et al. 2018 ACPD

6. Conclusions

- Satellite method allows for synoptic DMS emission estimates in heterogeneous, variable and remote Arctic Ocean.

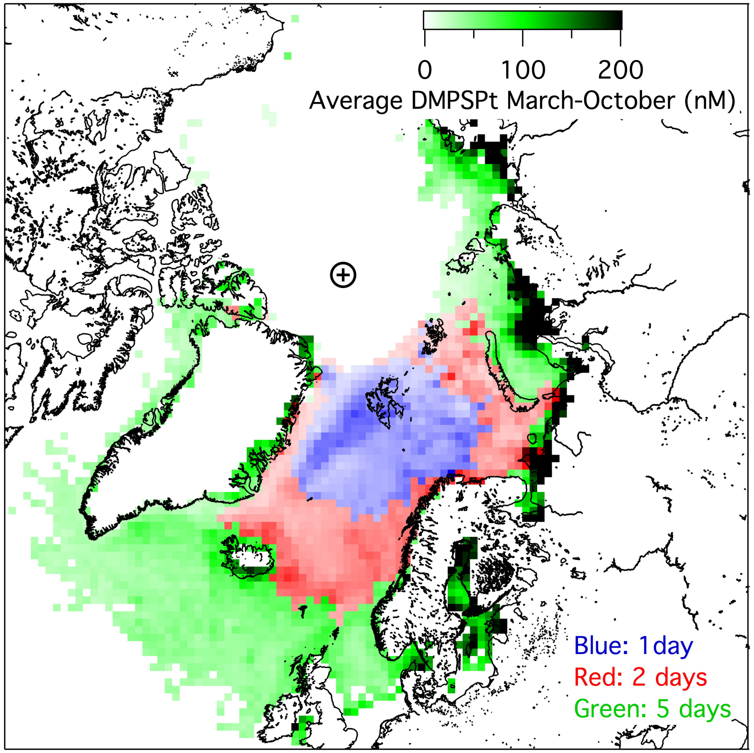
- Reveals…
    - Multidecadal EDMS trend driven by sea ice meltdown
    - Interannual EDMS changes driven by interplay between ice patterns and phytoplankton dynamics.

- Suggests need to move beyond “climatological approaches” in observational and model studies of DMS-climate feedbacks.

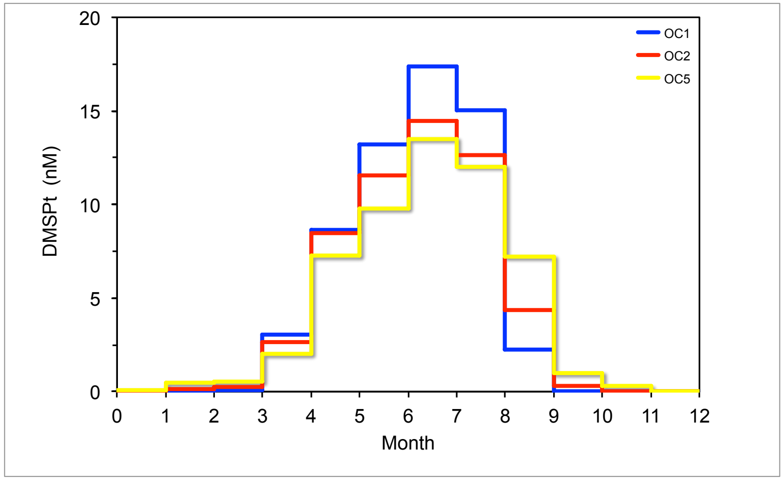
Thanks to: NASA Ocean Biology Processing group, NSIDC (Ice data), ECMWF (ERA-Interim), Maxime Benoît-Gagné, Martine Lizotte and Takuvik colleagues, CCGS Amundsen crew, Green Edge project

Ex. 1: aerosol back-trajectory studies

Atmospheric transport + surface properties



Inferences on aerosol processes



Heintzenberg et al. 2017 ACP